

CURRENT STATUS IN CAVITATION MODELING

by

Ashok K. Singhal and Ram K. Avva
CFD Research Corporation, Huntsville, AL

for presentation at
Open Forum on "Turbomachinery-Pumps-Cavitation"

11th Workshop for CFD Applications in Rocket Propulsion
NASA Marshall Space Flight Center, AL

April 20-22, 1993

Cavitation is a common problem for many engineering devices in which the main working fluid is in liquid state. In turbomachinery applications, cavitation generally occurs on the inlet side of pumps. The deleterious effects of cavitation include: lowered performance, load asymmetry, erosion and pitting of blade surfaces, vibration and noise, and reduction of the overall machine life.

Cavitation models in use today range from rather crude approximations to sophisticated bubble dynamics models. Details about bubble inception, growth and collapse are relevant to the prediction of blade erosion, but are not necessary to predict the performance of pumps. An engineering model of cavitation is proposed to predict the extent of cavitation and performance. The vapor volume fraction is used as an indicator variable to quantify cavitation. A two-phase flow approach is employed with the assumption of the thermal equilibrium between liquid and vapor. At present velocity slip between the two phases is selected. Preliminary analyses of 2D flows shows qualitatively correct results.

CFD Research Corporation



3325-D Triana Blvd. ■ Huntsville, AL 35805 ■ (205) 536-6576 ■ FAX: (205) 536-6590

CURRENT STATUS IN CAVITATION MODELING

by
A. K. Singhal and R. K. Avva

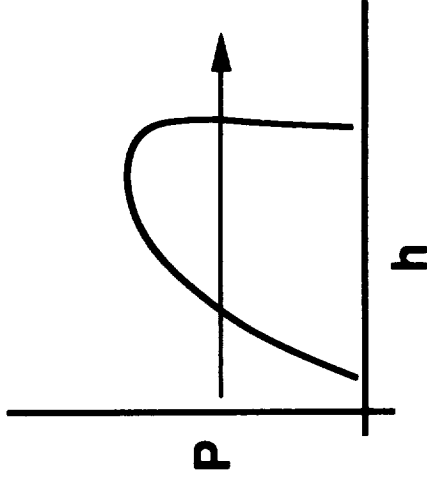
for Presentation at:
11th Workshop for CFD Applications in Rocket Propulsion
NASA Marshall Space Flight Center, AL

April 20-22, 1993

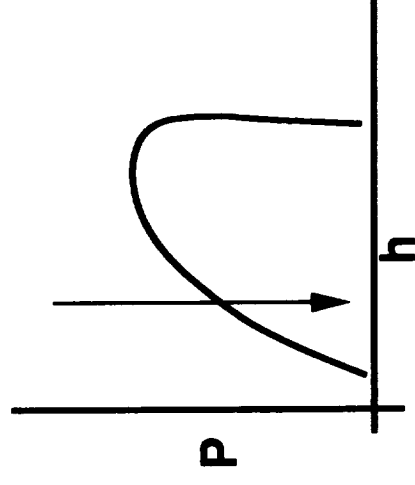
BOILING VS CAVITATION

CFDRC

Boiling is phase change at constant pressure due to addition of external heat.



Cavitation is phase change due to lowering of hydrodynamic pressure under adiabatic conditions.



HIERARCHY OF CAVITATION MODELS **CFDRC**

LEVEL	METHODOLOGY
1	Single-phase flow analysis; identify cavitated zones where $P < P_v$
2	Single-phase flow analysis; Set $P = P_v$ in regions where $P < P_v$; iteratively identify cavitated zones
3	Two-phase flow analysis with a vapor source equation
4	Two-phase flow analysis with bubble-dynamics equations

COMMENTS



- **Level 1 Approach:** O.K. but too conservative
- **Level 2 Approach:** too weak, and can be misleading
- **Level 3 Approach:** Acceptable and sufficient for performance prediction; Accuracy depends on Vapor Source Equation
- **Level 4 Approach:** Needed for accurate prediction of local damage sites of bubble bursting, *etc.*
- **Selected Approach:** Level 3

TWO-PHASE FLOW METHODS

CFDRC

Method	Governing Equations	Velocity Slip	Interphase Friction
Homogenous	Mixture momentum Mixture continuity Mixture enthalpy	0	—
Algebraic slip	Same as homogenous but with velocity-slip terms	Needs to be modeled	—
Two-fluid	Phasic momentum Mixture and/or Phasic continuity Mixture Enthalpy	$U_g - U_l$	Needs to be modeled
Eulerian-Lagrangian	Continuum equations for continuous phase Particle tracking	$U_g - U_l$	Needs to be modeled

DENSITY CHANGES IN ENGINEERING FLOWS **CFDRC**

$$\frac{\partial \rho}{\partial p} \approx \frac{1}{C^2}$$

C= Sound Speed

FLOW TYPE	$\rho_{\max}/\rho_{\min}$
Buoyant Flows	1.1
Transonic Flows	2.0
Supersonic Flows	10.0
Reacting Flows	20.0
Cavitating Flows	1000.0

Medium	Sound Speed (m/s)
Air	300
2 ϕ Diesel	1.6

- Large density variations give rise to stiff equations
- Smaller sound speed slows down information propagation
- Cavitating flows offer a very stringent challenge to numerical schemes

TEST PROBLEM

CFDRC

Geometry:	Axisymmetric Orifice; $D/d = 3$
Fluid:	Diesel
Flow Conditions:	$P_{\text{exit}} = 1 \text{ Bar}$; $T = 187^{\circ}\text{C}$; $\rho_l/\rho_v = 283$
Study 1:	Effect of varying inlet pressure
Study 2:	Effect of geometry change (rounded entrance; $\gamma/R = 15\%$)

CATERPILLAR INJECTOR ORIFICE

CFDRC

Steady State Analysis Pinlet = 2.5 bar



a. STREAMLINES

2.5e+05
2.3e+05
2.09e+05
1.89e+05
1.68e+05
1.48e+05
1.28e+05
1.07e+05
8.67e+04
6.63e+04
4.59e+04

b. STATIC PRESSURE

0.883
0.794
0.706
0.618
0.53
0.441
0.353
0.265
0.177
0.0883
0

c. VAPOR FRACTION

CATERPILLAR INJECTOR ORIFICE

Steady State Analysis Pinlet = 3.0 bar

CFDRC



a. STREAMLINES

3e+05

2.74e+05
2.49e+05
2.23e+05
1.98e+05
1.72e+05
1.47e+05
1.21e+05
9.54e+04
6.99e+04
4.43e+04

0.000131
0.000117
0.000104
9.14e-05
7.83e-05
6.53e-05
5.22e-05
3.92e-05
2.61e-05
1.31e-05
3.64e-12

b. STATIC PRESSURE

0.929
0.836
0.743
0.65
0.557
0.464
0.372
0.279
0.186
0.0929
1.49e-08

c. VAPOR FRACTION

CATERPILLAR INJECTOR ORIFICE

CFDRC

Steady State Analysis Pinlet = 10.0 bar



a. STREAMLINES

1e+06

9.04e+05

8.08e+05

7.12e+05

6.16e+05

5.2e+05

4.24e+05

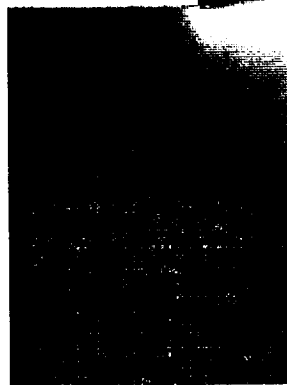
3.27e+05

2.31e+05

1.35e+05

3.93e+04

0.000252
0.000227
0.000202
0.000176
0.000151
0.000126
0.000101
7.56e-05
5.04e-05
2.52e-05
-7.28e-12



b. STATIC PRESSURE

0.965

0.868

0.772

0.675

0.579

0.482

0.386

0.289

0.193

0.0965

-1.49e-08

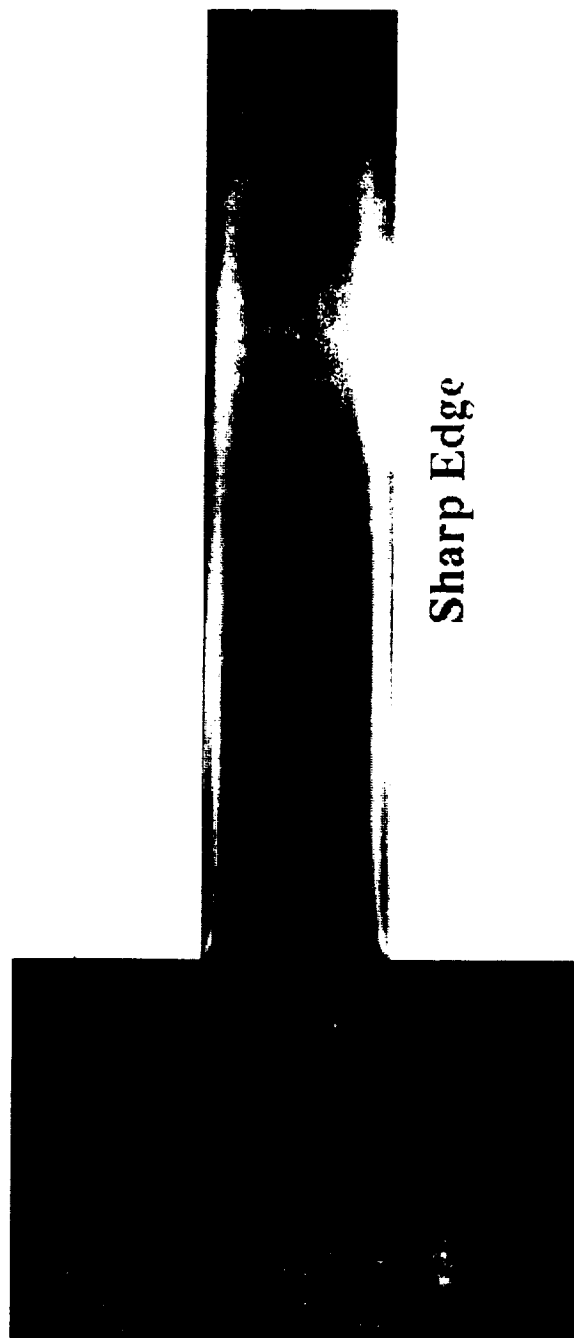


c. VAPOR FRACTION

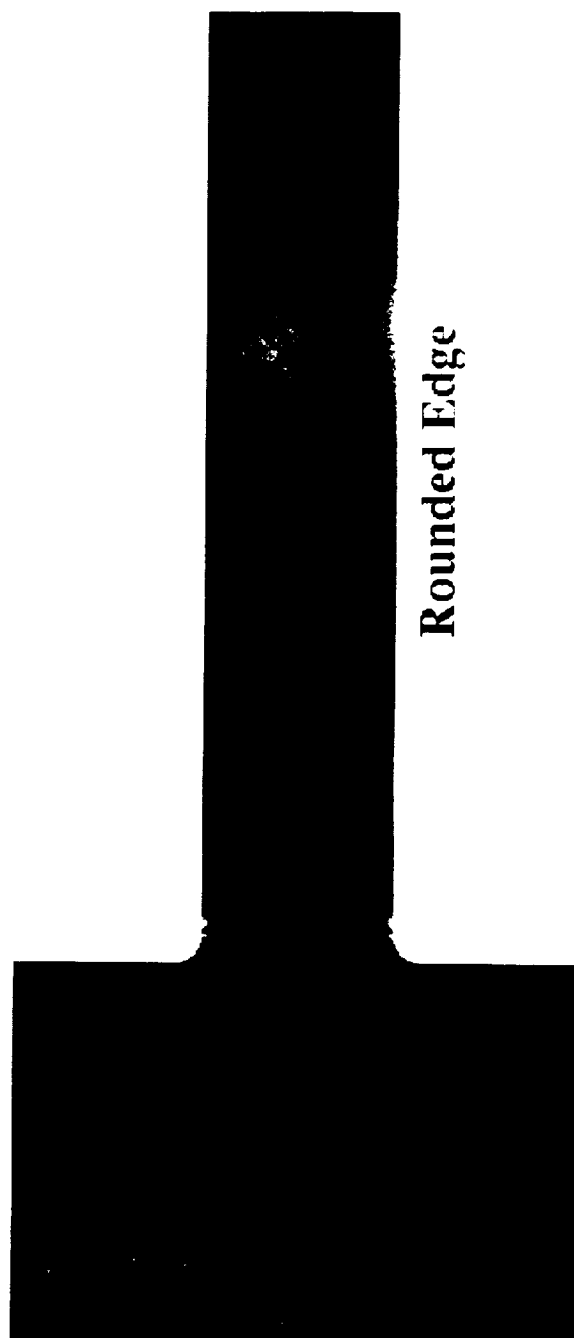
CATERPILLAR INJECTOR ORIFICE

CFDRC

Effect of Edge Shape on Void Fraction $P_{inj}=4 \text{ bar}$



Sharp Edge



Rounded Edge

- **Test Problem Results:**
 - 1) **As inlet pressure increases, state of cavitation changes from subcritical to supercritical.**
 - 2) **The rounded entrance reduces cavitation.**

- **Preliminary results are encouraging**

- **Considerable future work needed for:**
 - 1) **Robustness and accuracy improvements of basic method.**
 - 2) **Adaptation for complex geometries with additional body forces (e.g. due to rotation)**
 - 3) **Validation under a variety of flow conditions.**

